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ON THE USE OF THE AMPLIFIER

WITH OBSERVATIONS ON THE THEORY AND PRACTICE OF PHOTO-MICROGRAPHY, SUGGESTED BY THE DESIGN OF A NEW PHOTO-MICRO-CAMERA.*

BY GEO. W. RAFTER, M. AM. SOC. C. E.

In the proceedings of the American Society of Microscopists for 1884, there occurs a paper on Photography with High Powers by Lamplight, by Hon. J. D. Cox, of Cincinnati, Ohio. On page 100 I find the following: "Without pretending to be sure that my method is the best, I will still say that I have thus far got the best results by using the No. 1 ocular in the microscope and no other amplifier. It seems to me that after correcting the objective with care so as to present the best results to the eye directly, the satisfactoriness of the image which is thus produced, is best kept by using both objective and eye-piece in photographing, precisely as in looking, and with the same length of tube; changing nothing but the fine adjustment, to correct the focus for the position of the camera-screen. Such, at least, is the conclusion I have tentatively reached."

The distinguished standing of the author of the above, among microscopists, both American and foreign, gives it an authority which would not obtain if coming from a microscopist of less universal fame. It is with some little diffidence, therefore, that I presume to criticise his statement, and I cannot but regret that Mr. Cox has not given more in detail the experiments which have led him to this conclusion.

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* Originally published in the Rochester, (N. Y,) *Odontographic Journal* for July, 1887, also reprint 1887. Abstract with additional matter by the Author.

Certainly his conclusions are exactly the opposite of that indicated by theory, and they are equally opposed to the practical results obtained by Dr. Woodward.

In recent times the tendency to simplify photo-micrography has led to an ignoring of some of the fundamental principles of the art, and this present paper will have amply fulfilled its mission, if it succeeds in directing the attention of the more advanced workers to certain indispensable conditions, without an observance of which success cannot possibly be obtained.

Dr. Woodward, as long ago as 1866, pointed out the proper method of procedure for obtaining the best photo-micrographic results, and at that time laid down general principles which represent so far as the English literature of the subject is concerned, the first *complete* system of photo-micrographic practice.

I am aware that previous to this time much creditable work in photo-micrography had been done in England and on the continent of Europe, but Dr. Woodward's system is far more complete than anything bearing upon the subject which had been produced up to that time. It is specially valuable that it is the first recognition of the value of the achromatic concave amplifier for obtaining additional amplification instead of by use of an eye-piece, and it is due to this discovery* alone that he was able to make in the later years of his work the magnificent series of photographs of the test diatoms, and other difficult subjects which still remain on the whole unequalled by the productions of any other worker, and are likely so to remain for a long time to come, monuments to the photographic genius of Dr. Woodward. To him, therefore, may fairly be awarded the credit of having made photo-micrography as a practical art possible, of having, indeed, put it on such a basis, as to render easy the production of photographic representations of microscopic objects on a large scale. Previous to his day it was in effect only a scientific plaything.

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*Dr. Woodward states that he obtained the suggestion of such use of the amplifier from Mr. Lewis M. Rutherford.

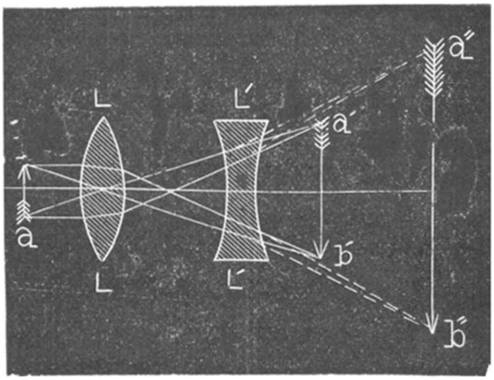

Fig. 1.

Referring to Fig. 1, let L L be a double convex lens representing the lens system of an objective ; a b an object between the lens and the principal focus on that side; a a′ and b b′ secondary axes drawn from a and b respectively through the optical center. Also consider parallel rays of light radiating from a and b; these, after passing through the lens are refracted to a′ and b′, meeting the secondary axes a a′ and b b′ at those points; conjugate foci are formed at a′ and b′ whose corresponding initial foci are a and b. From this results the formation at a′b′ of a real magnified image of the object a b. It is evident from the figure that the size of a′b′ is to the size of a b, as their distances from the optical center respectively.

Suppose, however, that the double concave lens L′L′ is so placed as to intercept the rays from a b after they have passed through L L and before coming to a focus at a′ and b′. By such interception the rays are made more divergent, and the image instead of being formed at a′b′ is formed at a″ b″. It is moreover apparent from the figure that if L′L′ is placed in any other position in reference to L L, that the image a″b″ will still be formed, and that it will advance or recede from L L as L′L′ advances or recedes.

It is also apparent from what has gone before that if the object a b is brought nearer to L L, the divergence of the axes a a′ and b b′ will be increased and a new image may be farther projected to any required distance (within limits) by proper placing of the lens L′L′.

Fig. 1 therefore illustrates the formation of photographic images when photographing with the naked objective or with the concave amplifier.

The practical fact has been repeatedly observed that when using the naked objective in photo-micrography, for considerable extension of the camera, the objective is brought so much nearer the object than its normal working distance that aberrations are introduced which frequently completely destroy the sharpness of the image, or in the case of high powers, the objective is brought so near the object, that, with the short working distance which such objectives always have, it is found impossible to focus at all for any considerable extension of screen. This difficulty has usually been met by the use of the eye-piece, but this, unfortunately, introduces an entirely new set of conditions and difficulties, which have been found more impossible to reconcile than the comparatively simple ones which occur when using the naked objective.

From the diversity of opinion which prevails as to the relative advantages of these different methods of projecting the photographic image, I have been led to suppose that the theory of the matter is not generally understood, and the optical part of this paper is therefore an attempt to set forth the theory in its proper light.

With the amplifier, however, the difficulties above enumerated are immediately removed, all that is required being to find by trial such a position of L′ L′ as will give, for any position of a b with reference to L L, a distinct image at any required position of the screen a″ b″.

Fig. 2 illustrates the principles involved in the projection of an image with the eye-piece. a b is the object, and L L the lens system of the objective as before, and a′b′ the real aerial image formed by the objective. L′L′ represents the eye-piece. The rays after coming to a focus at a′b′, and forming the real image a′b′, diverge, and, on undergoing refraction in passing through L′L′, are again brought to a focus and produce the image a″b″, which may be received upon a screen. From the preceding principles it is evident, that in producing a photographic image by this method, there is not only great loss of light, but also great loss of distinctness of the image. From the theory of the formation of conjugate foci on principal and secondary axes it is apparent, that, on and in the vicinity of the principal axis, the image is more distinct than at points off of the principal axis, and that the farther any point of the image is removed from the principal axis the greater will be the indistinctness. Again the indistinctness of the image will increase in proportion to the amount of divergence of the secondary axes passing through the extremities. Moreover the Huyghenian eye-pieces, which are generally used for this purpose, are not really achromatic combinations. Their apparent achromatism is produced, not by bringing the red and violet images into true coincidence, but by causing one to cover the other as seen from the position of the observer's eye.

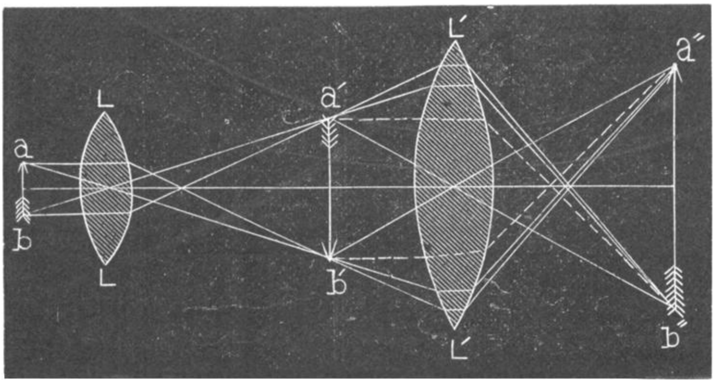

FIG. 2.

But the conditions, which obtain in vision through an eye-piece are quite different from those which obtain when an image is projected through an eye-piece upon a screen. So different are they, indeed, that when the microscope is focussed for ordinary microscopic vision through an eye-piece, there is no position of the screen, which will give a distinct image without changing the position of the focus, either of the objective or the eye-piece, and such change of necessity introduces conditions which effectually destroy the apparent achromatism of the eye-piece as used for microscopic vision. Fig. 3 in comparison with Fig. 2 will show the difference between projection upon a screen and ordinary microscopic vision through an eye-piece. Referring to Fig. 3, let L L be the eye lens of an eye-piece, E E is taken to represent the lenses of the human eye and R R the retina. r r′ r′′ r′′′ are rays of light which have undergone refraction through the field lens of the eye-piece, and which are brought to a focus at a and b, forming the real image a b. After forming the image a b the rays r r′ r′′ and r′′′ pass on towards L L and are farther refracted, after which they pass into the eye E E, forming on the retina R

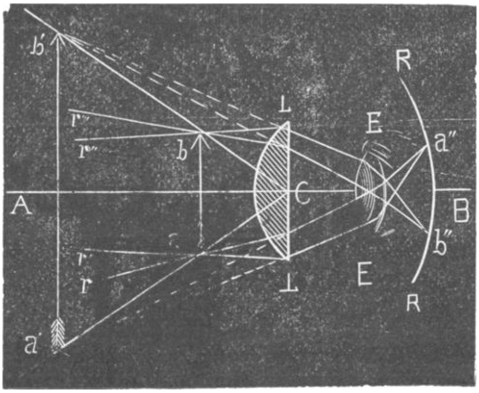

FIG. 3.

R the image a′′ b′′, which by the theory of vision is seen under such a visual angle as to apparently project it to a′b′. The conditions for distinct vision with the eye-piece are that the rays r r′ r′′ and r′′′ after refraction by the lens L L shall become *nearly* parallel, but converging towards A enough to meet the secondary axes through a and b (that is, the axes a C and b C) at some points, a and b′, where the virtual image a′ b′ is formed. In microscopic vision through an eye-piece, therefore, we do not see the real imageof the object, but an image of an image, or the virtual image.

It is apparent moreover from an inspection of Fig 3 that under no condition could the rays r r′ r′′ r′′′ be made to converge after passing through L L; they are made divergent, and, will always remain so, without another lens is interposed, or else that the relative positions of eye-piece and objective are so readjusted as to cause them to converge after passing through L L. It follows from this that when the adjustment is made for vision there is no position of the screen which will give a sharp image. The truth of this may be readily demonstrated by experiment, when it will be found that with the screen very close to the eye-piece an indistinct image is formed, and, leaving the relation of eye-piece and objective the same, the farther the screen is removed from the eye-piece the more indistinct the image becomes. This accords perfectly with the theory as exhibited by Fig 3.

Referring again to Fig. 2, it may be seen that the converse of the above proposition is equally true that, when the adjustment is made for the projection of an image, it is equally impossible to get microscopic vision.

We also see by comparing Figs. 2 and 3 why the change of combination necessary to project an image upon the screen must, of necessity, destroy the apparent achromatism of the eye-piece. The correction is made, as above stated, for bringing the violet and blue spectra, not coincident, but one above the other, when the eye-piece is used for vision. But such use renders rays divergent, which in projection of an image are required to be convergent. It would seem to follow, therefore, that these spectra will separate in proportion, interfering materially with the perfection of the image. The essential truth of this statement may be readily determined by experiment.

In any case, in photographing with the eye-piece, changes in distance of screen from object should be compensated for, not by changing the focus of the objective, but by changing the position of the eye-piece. The objective being once set to such position as gives the best image with normal length of tube and eye-piece, should then be left undisturbed, and the adjustment for position of screen made by change of position of eye-piece.

This practical difficulty in the use of eye-pieces for projection appears to have occurred to the eminent German optician, Carl Zeiss, of Jena, as I find in his recent catalogue an account of a series of what he calls "projection eye-pieces." It would have been some little gratification to optical students had Herr Zeiss seen fit to set forth more clearly the optical principles involved in these new projection eye-pieces. Possibly he has done so in some of the German periodicals, but thus far I think no such exposition has appeared in any of the American or English microscopical journals.

Lacking such complete exposition of the optical principles involved, a few provisional criticisms are offered.

In the first place, calling them eye-pieces is evidently a misnomer, as, referring to the above description, it appears that they cannot be used for microscopic vision. The preliminary adjustment of the specimen must be made with an ordinary eye-piece, after which the projection eye-piece is placed in position. This changing of eye-pieces is in itself a serious objection in high power work where the slightest disturbance of the apparatus leads to such disarrangements as must necessitate a new adjustment. All practical photo-micrographers will agree with me, therefore, that any process which necessitates the removal of one piece of apparatus, and the substitution of another in its place is for high power work fundamentally defective. The inevitable disturbance of apparatus which will occur in making such changes, leads not only to loss of time, but usually to deterioration of the negative. Nor do I in making this criticism overlook the fact that the focusing of the object is, according to Herr Zeiss' description, completed after such change of eye-pieces. The criticism is made on the broad ground that any substitution of apparatus whatever, is undesirable, provided the best results can be obtained without such substitution. That such results can be obtained in a more satisfactory way, I will attempt to show in the sequel.

Again, the description in general terms answers to that of a Huyghenian eye-piece, that is, they consist of a convex lens (the field lens presumably), and a compound system (the eye lens presumably), with a diaphragm between them. They differ from the Huyghenian eye-pieces in this, that the compound system is truly achromatic, and that it is made adjustable in reference to the diaphragm. Such adjustment evidently having reference to the bringing of the rays to a focus as shown in Fig. 2.

I have no doubt but that the making of such an achromatic combination would materially improve the performance of eye-pieces when used in photo-micrography. However, the objection to the use of *any* eye-piece still remains valid. The crossing of the rays after passing through the eye lens, and the consequent great obliquity which they attain, must still result in unnecessary loss of light and considerable impairment of the sharpness of the image. Certainly until some expert worker shall have actually produced by such an arrangement photo-micrographs finer than those made by Dr. Woodward, we are justified in assuming that the use of the simpler optical combination of the adjustable achromatic amplifier is, on the whole, preferable.*

It farther appears, from this point of view, that Herr Zeiss has unnecessarily complicated his projection eye-pieces by making the compound system adjustable with reference to the diaphragm. The really important point, it would seem, was to make them achromatic and then, having once set the objective to normal working distance, to compensate for changes in position of screen by withdrawing the eye-piece. From present information it would appear that equally satisfactory results could be so obtained with some little gain in the matter of simplicity.

At any rate the result of a trial of this appliance will be awaited with no small degree of interest.†

In order to exhibit with clearness the relation between working distance and length of tube I have taken a Bausch & Lombe three-inch professional objective of 12° angular aperture, and made the approximate measurements recorded in the following table. They serve to exibit, in a general way, the great influence on working distance exercised by length of tube. These measurements are made with the naked objective:

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* In the J. of the Roy. Micr. Soc., for Feb. 1887, page 20-34, Prof. Abbe has a paper on Improvements of the Microscope with the aid of New Kinds of Optical Glass. Referring to the use of projection eye-pieces, rather than the amplifier, for correcting the aberrations produced by distance of the screen, he cites as a chief objection to such use of the amplifier, the "minute and troublesome manipulation in the adjustment, if a good correction of the objective is to be secured."

Attention may be directed to the fact that the addition to the photo-micro-camera of specific mechanical appliances for instantly making this correction, entirely disposes of the above objection, and to the farther fact, that, inasmuch as Prof. Abbe has not given any other objections to the use of the amplifier for this purpose, it must be considered that the above is the chief objection that can be urged.

† Am. J. Sci. and Arts, 1861, xxxii, 186. On the practical Application of Photography to the Microscope, by Prof. O. N. Rood.

Prof. Rood states that in the course of his investigations he had three eye-pieces constructed. No. 1, on the general Huyghenian plan, the eye lens being an under corrected *achromatic*, in which the distance between the eye lens and field lens could be varied at pleasure, as advised by Amici. Prof. Rood says the general performance of this eye-piece seemed somewhat better than the plain Huyghenian eye-pieces with which it was compared.

No. 2 was a Kellner eye-piece in which the distance between the lenses could be varied.

The performance was good.

No. 3 consisted of two achromatic lenses combined in the Huyghenian manner. This, I infer from Prof. Rood's statement, to have been inferior.

It appears, therefore, that Herr Zeiss' projection eye-pieces hardly have the merit of novelty.

Magnification = Diameters.	Length of Tube = Length of Camera in Feet.	Working Distance in Inches.
——	0.83*	1.96
——	1.15	1.67
10	1.97	1.44
20	3.81	1.33
30	5.64	1.29
40	7.47	1.27

It appears from this table that in extending the camera from ten inches to seven and one-half feet, the working distance of such an objective is reduced from 1.96 inches to 1.27 inches, or 0.69 of an inch.

The normal working distance of a wide angled four system homogeneous immersion $\frac{1}{8}$ objective is about 0.02 of an inch, and of a similar $\frac{1}{12}$ about 0.0133 of an inch†. If the decrease in working distance of either objective is at all proportional to focal length, it is evident that difficulty would be found in working either of them at an extension of from seven to eight feet. That such difficulty exists is within the experience of all workers in this department, but I am not aware that any precise measurements have been made of such decrease for higher powers. Approximate results can, of course, be obtained by computation.

The fallacy has prevailed to some extent that the concave amplifier may be legitimately used to increase the working distance of objectives. A little consideration will convince one, however, that such use can only result in an impairment of the image.

Again, referring to Fig. 1, consider a′ b′ as a fixed position at which it is desired to receive the image, as, for instance, in microscopic vision a′ b′ may be taken as at the diaphragm of the ocular. With the amplifier L′ L′ in place, the image a′′ b′′ may be made to move towards the position a′ b′ either by moving the lens L′ L′ towards L L (within limits), or by moving the object a b away from L L. Such moving of a b away from L L is, in effect, an increase of the working distance of L L. It is evident, however, that by so moving a b away from L L we immediately disturb the normal working of the objective, and, independent of the theoretical condition, a practical trial will readily convince one that such increase is followed by impairment of the sharpness of the image.

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*This measurement is made with normal working tube of ten inches, as used by the Bausch and Lomb Optical Co., who measure the ten inches from the focal plane of the objective to the diaphragm in the ocular.

†For tabulating working distances of four system homogeneous immersion objectives from $\frac{1}{4}$ to $\frac{1}{25}$, as made by Mr. Gundlach, see Catalogue of Gundlach Optical Co.

By way of farther illustrating this part of the subject I have made a series of approximate measurements of the working distance of a so-called two-inch objective of a tabulated aperture of 15°. I say so-called two-inch, because, while this is the maker's designation, it appears on the application of a Cross formula* to have in fact only 1.455 inches focal length instead of two inches as called for.

The approximate measurement of the so-called two-inch is given in the following table:

l, in inches.	m	$f=\frac{m\,l}{(m+1)^2}$
48	31	1.453
60	39	1.462
72	47.6	1.451
84	56	1.447
96	63.6	1.463

Mean = 1.455.

The result f will be in the same unit as l.

The working distance of the above objective with ten-inch tube is 0.96 inch.

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* See paper on the Focal Length of Microscope Objectives, by Charles R. Cross, in the Journal of the Franklin Institute for June, 1870, 401; also reprint in Month. Micr. Jour., 1870, IV. 149. Also, for farther discussion of the same subject, paper by Dr. Woodward, Remarks on the Nomenclature of Achromatic Objective for the Compound Microscope, in Am. J. Sci. and Arts, 1872. 3s, III, 406; also reprint in Month. Micr. J., 1872, VIII, 66; also Am. J. Micr., 1881, VI, 77.

At an extension of camera screen of 6.0 feet the working distance of the naked objective is 0.76 inch.

With the camera screen still remaining at an extension of 6.0 feet, and with an amplifier of 6 inches negative focus so placed that the front of the amplifier lens is 4.75 inches back of the posterior lens of the objective, the working distance is again brought to 0.96 inch.

It follows, therefore, that this position gives the proper relation of the amplifier and this particular objective for producing the best photographic results at an extension of 6.0 feet.

The following series show the effect of amplifier in increasing the working distance beyond the normal amount.

With amplifier immediately back of posterior lens of objective (about one inch away), and with camera screen extended to 8.0 feet, the working distance is found to be 1.15 inch.

With same conditions, except that screen was at 3.0 feet, the working distance is 1.22 inch.

From a consideration of Figs. 1 and 2 and the above measurements, it appears evident that when the amplifier is nearer the objective than the position for normal working, the working distance of the objective is increased.

The converse is equally true, that when the amplifier is placed at a greater distance from the objective than the position of normal working, the working distance of the objective is decreased, but not in so great a degree as when the naked objective is alone used. For instance, with the amplifier at 12.0 inches from the posterior lens of the objective it appears that the working distance is 0.89 inch. At the same distance this objective gave, when used without the amplifier a working distance of 0.76 inch as above stated. The importance of having ready means of adjusting the amplifier is therefore rendered apparent by these measurements.

In order to get such ready means of adjusting the amplifier and to develop a photo-micro-camera which would answer all the demands which might be made upon it, I have designed the apparatus shown in Fig. 5. This is really a photo-micro-camera complete within itself, and not a microscope and camera combined. I found, early in my experience as a photo-micrographer that one instrument could not be made to do the work of two, and that it was only possible to use photography as a real aid to microscopical investigations by having photo-micrographic apparatus, which, in addition to being always ready, also possessed the quality of easy adjustment to any and all kinds of work. The present design possesses not only all these qualities, but it can also be furnished at a price quite within the reach of any person really desiring such an aid to scientific investigation.

A reference to Fig. 4 in conjunction with Fig. 5 will show the novel points.

A in Fig. 4 is the stage, B is a nose-piece which carries the objective and also a removable collar carrying the tube C, which is supported by a removable pillar shown in Fig. 5. Inside the tube C is a second tube made to work back and forth very easily and carrying at its lower end a right angle prism set for total reflection. This tube is of such a length as to give, when in position for receiving the image, from the objective through the prism a length of 10 inches measured along the optical axis. The eye-piece in the outer end has cross-hairs set in the diaphragm, so adjusted, in relation to the prism at the other end, as to correspond with cross-lines on the ground-glass of the camera screen. The tube C, therefore, gives the opportunity to examine the object under the conditions of microscopic vision, and with the cross-hairs in the eye-piece farther enables the operator to exactly center the object on the screen.

F is an adjustable tube carrying within it a second tube, which may be slid back and forth. This interior sliding tube has an adapter at the front end into which an amplifier may be screwed, and the whole racked back and forth by the pinion E, which also carries between the thumb-screw and the body a pulley over which a band can be placed for working the amplifier from the rear of the camera screen.

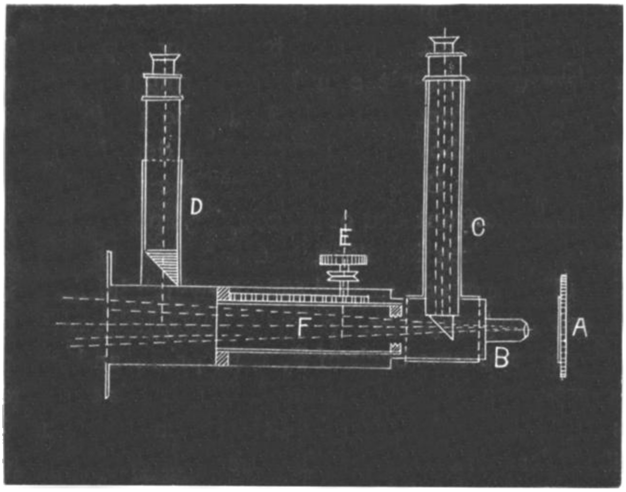

FIG. 4.

This inner tube also has a graduation on the side in order to facilitate recording the proper position of the amplifier for various extensions of the screen.

In working with high powers where it is desirable to use the amplifier, the objective is set to normal working distance by observing the object through the tube C. The operator then, from the rear of the camera, by use of the band over the pulley at E, racks the amplifier to such a position as to give a sharp and distinct image on the ground-glass, the objective in the meantime remaining undisturbed. It is of course understood that after having adjusted the objective to normal working distance, the inner tube at C, carrying the prism and eye-piece, has been sufficiently withdrawn to allow the rays of light to pass unobstructed to the camera screen. This gives us, almost instantly, the conditions which have been shown above to be necessary for production of the highest results, and with this apparatus the most difficult tests are easily photographed.

When working with low powers, the amplifier is not essential for the production of sharp images, and the tube C and nose-piece B are removed by simply slipping off the collar from the nose-piece and unscrewing the nose-piece from the body, an operation which may be performed in a moment. Fig, 6 shows these parts when detached.

After removing B and C, the inner tube F is drawn forward so that the front end of it occupies, approximately, the position of B when in place, and the objective is screwed into the adapter in end of said tube F, which in high power work carries the amplifier.

D is a second tube back of F, with prism and eye-piece with cross-wires, precisely as in C. With this tube the object is examined and centered on the ground-glass, as above described, for work with C. After such centering, the focusing is completed either by use of the band passing over the pulley at E, or by the use of the long rod and fine adjustment to be described below. The inner tube at D is shown as dawn back in such position as to allow the rays of the light to pass unobstructed to the screen.

The camera itself has both bellows and base made in sections each two feet in length. The sections of the bellows can be readily removed, or additional sections inserted, when great extension is required.

A section of the base is shown in the foreground of Fig. 5 and the method of attachment may readily be inferred from the cut. The brass rod for working the fine adjustment, is shown passing through the middle of said section of base in foreground of Fig. 5. The ends of this focusing rod are attached by an automatic coupling so made that there is no chance for lost motion.

The plate and screen holder is racked back and forth as clearly shown in cut.

On the side of the base, is a graduation in feet, tenths and hundredths of a foot which enables one to record positions of the screen for producing given magnifications easily.

The fine motion is communicated to the stage, and not to the objective, as is clearly shown in Fig. 5.

The camera, as shown in the cut, admits of an extension of 8 feet, and sections of base and bellows similar to those above described can be added, extending it almost indefinitely. The extension above given will, however, answer all ordinary demands.

In its present form the camera takes a 6½ × 8½ plate, and all sizes less than that down to the smallest.

This apparatus has been specially designed with reference to doing photo-micrographic work of a high character with the greatest possible economy of time. It is for this purpose that the second prism tube has been added specially for low power work without the amplifier, and I have no difficulty in making with this camera a half dozen negatives in an evening, when working with lamplight and the amplifier, or from eight to ten in the same time when working with low powers and without the amplifier, in each case doing my own developing. In working by sunlight, where much shorter exposures are required, the same length of time gives an additional amount of work.

In case one has an extra microscope, the new apparatus for working the amplifier may be adapted to it at moderate expense, and by construction of the bellows and extension arrangements, as above described, the more important advantages of the camera gained.

For rapid work the camera should be placed on a shelf on one side of the room, at such a height as to bring the horizontal prism tubes level with the operator's eye. The position of the camera at one side of the room insures economy of space and does away with the objection that the

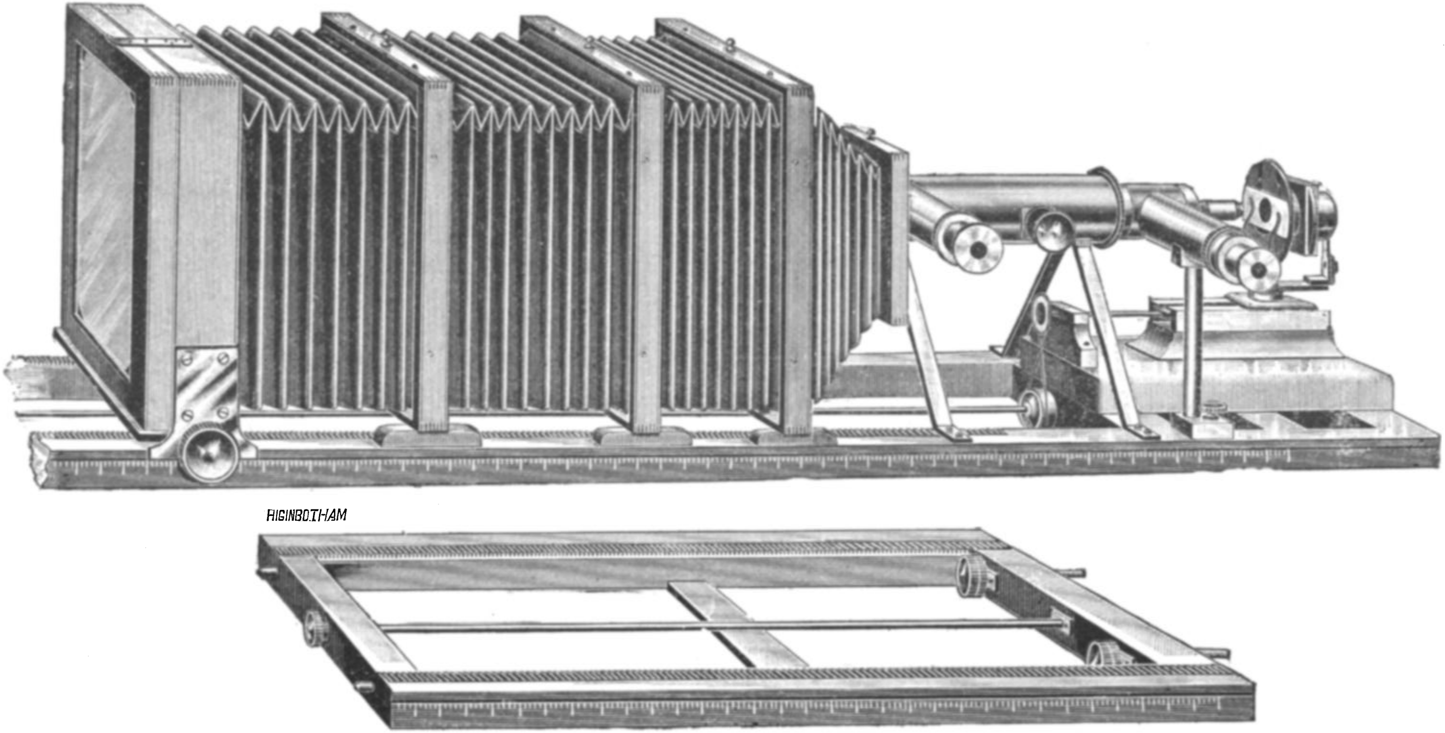

Fig. 5. — The Professional Photo-Micro-Camera.

camera, even though of considerable size, takes up much room.

When it is intended to work by lamplight only, it will not matter which side of the room is used for the purpose, and the operator may locate the camera to suit his surroundings; care must be taken, however, to have the graduation of the base on the side away from the wall. If one has plenty of room, the best arrangement would, of course, be to erect a shelf on horses in the middle of the room, so that the camera is accessible on both sides.

When it is intended to work by sunlight, the camera must of necessity be at either the east or west side of a room with an exposure to the south, or when economy of space is of no importance it can be conveniently placed in front of a window facing the south in which may be fitted up the necessary arrangements for heliostat, mirrors or condensing lens.

In any case the surroundings will decide to some extent just what arrangement will be adopted.

The following are, as far as I know, the new features embodied in this camera:

1.—The application of specific appliances for moving the amplifier back and forth, in order to find by trial, for any given extension of the camera, the best position of the amplifier for projecting the image upon the screen.

2.—The application of two horizontal prism tubes, one for use with high powers, and the amplifier, and the other for use with low powers without the amplifier.

3.—The detachable nose-piece and prism tube for high powers only, Fig. 6.

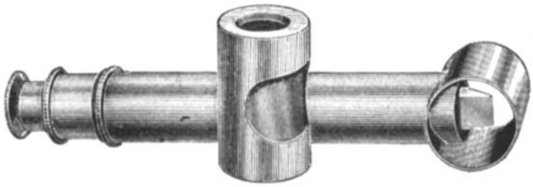

FIG. 6.

4.—The cross wires in the diaphragm of the eye-piece of the prism tube, giving an immediate centering of the object on the camera screen.

5.—The making of the bellows in sections, in such manner as to admit of their easy removal or of a ready indefinite extension.

6.—The making of the base in sections in combination with the focusing rod, connected by an automatic coupling.

7.—The plate holder which admits of all sizes of plates from the maximum of 6½×8½ to the smallest without the use of kits.

Another new feature, which, however, is not specifically claimed, is this: If one has a prejudice in favor of photographing with an eye-piece, or if from motives of economy, one desires to dispense with the amplifier and work with the eye-piece, this may be done by simply inserting an eye-piece in the back end of the amplifier tube. For so working, an adjustable nose-piece for carrying the objective without the high power prism tube may be furnished, thus dispensing with one of the prism tubes, which, however, can be added at any time by change of nose-pieces. The object can be still centered by the posterior prism tube which is permanently fixed to the body, and the projection of a sharp image upon the screen completed by moving the eye-piece with the pinion E, Fig. 4.

The general claim is made, therefore, that this camera embodies more nearly all the conditions necessary for rapid and successful work than anything heretofore produced.

I have no doubt, however, but that a very considerable improvement can still be made, and confidently expect in view of the great interest now centering in photo-micrographic work, that the next few years will develop such improvements.